Soft-Collinear Effective Field Theory

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CUSO Graduate Course, EPFL, Nov. 2015
Tools for QFT computations

- Expansion in the interaction strength: perturbation theory
- Expansion in scale ratios: Effective Field Theories
- Numerical methods: lattice simulations
- Toy models: solvable models, SUSY theories, AdS/CFT
Jet physics at the LHC

Many scale hierarchies!

\[ \sqrt{s} \gg p_{\text{Jet}}^T \gg M_{\text{Jet}} \gg E_{\text{out}} \gg m_{\text{proton}} \sim \Lambda_{\text{QCD}} \]

→ Soft-Collinear Effective Theory (SCET)
Outline of the course

• Invitation: perturbative QCD and effective field theory
• The method of regions
  • a simple example
  • Scalar Sudakov form factor
• Introduction to perturbative QCD / introduction to EFT
• Scalar SCET
  • factorization for the scalar Sudakov form factor in d=6
• Generalization to QCD
Outline […]

• Sudakov form factor in QCD
  • Resummation by RG evolution
• Drell-Yan process near partonic threshold
• Factorization for generic Drell-Yan
• Factorization constraints on infrared divergences in $n$-point amplitudes
• Factorization and resummation for cone-jet processes (1508.06645 with Neubert, Rothen and Shao).
Literature

A few selected original references are:

Original SCET papers (using the label formalism):


SCET in position space:

Sample collider physics applications:

Factorization analysis for DIS, Drell-Yan and other processes


Threshold resummation in momentum space using RG evolution, threshold resummation for Drell-Yan


EFT analysis of the IR structure of gauge theory amplitudes


Factorization for cone-jet processes

- TB, M. Neubert, L. Rothen and D.Y. Shao, *An effective field theory for jet processes* 1508.06645
Will follow this book for parts of the lecture, in particular for the construction of the EFT.

The book also contains a chapter with a review of the many application of SCET

- Heavy-quark physics
  - B-physics, top physics, unstable particle EFT
- Collider physics
  - Event shapes, jets, threshold resummation, transverse momentum resummation, electroweak Sudakov resummation
  - Others: Heavy-ion collisions, soft-collinear gravity, …

and a guide to the associated literature.
Alternative SCET introduction

edX online course on effective field theory by Iain Stewart, see https://www.edx.org/course/effective-field-theory-mitx-8-eftx

- Video lectures on SCET and other EFTs
- includes a set of TASI lecture notes on SCET by Christian Bauer and Iain Stewart
- Uses and introduces the label formalism.
$R$-ratio
$e^+ e^- \rightarrow$ hadrons: cross section

![Graph showing various hadron production cross sections vs. square root of energy in GeV. Peaks at $\rho$, $\omega$, $\phi$, $J/\psi$, $\psi(2S)$, $\Upsilon$, and $Z$ states.]
The green dashed line is our LO prediction after inclusion of quark masses and Z-exchange. Red line includes NNLO QCD corrections.
b-quark threshold region

Figure 46.7: $R$ in the light-flavor, charm, and beauty threshold regions. Data errors are total below 2 GeV and statistical above 2 GeV. The curves are the same as in Fig. 46.6.

Note: CLEO data above $\Upsilon(4S)$ were not fully corrected for radiative effects, and we retain them on the plot only for illustrative purposes with a normalization factor of 0.8. The full list of references to the original data and the details of the $R$ ratio extraction from them can be found in [arXiv:hep-ph/0312114]. The computable data are available at http://pdg.lbl.gov/current/xsect/.
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Below charm threshold

![Graph showing cross sections and related quantities for u, d, s, ω, ρ, ρ', and other particles.](image)

- **3 loop pQCD**
- **Naive quark model**

Sum of exclusive measurements

Inclusive measurements

Note: Crystal Ball, CLEO II, DASP, HELA, ARGUS, CUSB, DHHM, Crystal Ball, CLEO, II, DASP, LENA, Mark-I, Mark-II, Mark-I + LGW, BES, Crystal Ball CLEO II DASP LENA, ARGUS CLEO CUSB DHHM, Crystal Ball CLEO II DASP LENA, Naive quark model, Crystal Ball CLEO II DASP LENA.
\[ R = 1 + a_s + (1.9857 - 0.1152 n_f) a_s^2 + (-6.63694 - 1.20013 n_f - 0.00518 n_f^2) a_s^3 + (-156.61 + 18.77 n_f - 0.7974 n_f^2 + 0.0215 n_f^3) a_s^4. \]
$R = K \, N_c \, \sum_{q} e_q^2$ and \( \bar{K} = 1 - K \)

Deviation from QPM result in QCD for $e^+ e^-$ total cross-section, $\sqrt{s}=33$ GeV \( \Lambda^{(5)} \) (two loop) = 230 MeV.